Contents

1 Common Neurosurgical Procedures

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GENERAL PRINCIPLES

In general, when caring for neurosurgical patients perioperatively, hemorrhage at the surgical site can be more injurious than in other specialties. Therefore a strong emphasis is placed on maintaining coagulation and platelet parameters pre- and postoperatively for these patients. As a rule of thumb, surgeons are comfortable with most neurosurgical procedures if the platelet count is greater than 100,000 and the INR is less than 1.5. In addition, patients will often need to hold antiplatelet and anticoagulant agents 1–2 weeks preoperatively. Whether from consumption, nutritional deficiency, alcoholism, or other bleeding disorders, it is important for physicians to keep these parameters in mind to prevent devastating hemorrhages in both cranial and spinal procedures.

VENTRICULOPERITONEAL SHUNTING

Indications

Hydrocephalus is one of the most common and dangerous problems encountered in neurosurgery. In accordance with the Monro-Kellie doctrine, inappropriate accumulation of cerebral spinal fluid directly impacts intracranial blood volume, brain parenchyma, and can cause neuronal dysfunction and/or disruption of cerebral blood flow.

Commonly encountered causes of hydrocephalus include subarachnoid hemorrhage, meningitis, neoplasm, meningeal carcinomatosis, congenital hydrocephalus, idiopathic intracranial hypertension (pseudotumor cerebri), and normal pressure hydrocephalus.

Hydrocephalus is essentially a plumbing problem and is treated with cerebrospinal fluid (CSF) diversion. Temporary diversion is achieved with a lumbar puncture, lumbar drain, or external ventricular drain. Persistent hydrocephalus requires permanent drainage with a shunting procedure or endoscopic third ventriculostomy in cases where an intracranial obstruction can be internally bypassed.

Table 1.1 Perioperative signs associated with procedural complications, followed by immediate next steps in workup/management

Procedure	Signs/symptoms	Associated complication	Immediate diagnosis and intervention
Ventricular peritoneal shunt	Lethargy/headache/neurological deficit Sudden focal neurological deficit Severe abdominal pain/fever/sepsis/nausea or vomiting Coughing/shortness of breath/desaturation	Shunt failure Pericatheter hemorrhage Bowel perforation Pneumothorax	Head CT to assess ventricles Head CT to assess size of hemorrhage Upright abdominal x-ray or CT abdomen, general surgery consult Chest x-ray and general surgery consult for chest tube
Craniotomy/Craniectomy	Decreased consciousness/focal neurological deficit	Surgical bed hemorrhage, hydrocephalus	STAT head CT
Anterior cervical discectomy and fusion	Difficulty breathing Hoarseness/difficulty swallowing Difficulty swallowing/fevers/sepsis	Hematoma, soft tissue edema Recurrent laryngeal nerve injury Esophageal injury	Emergent NS evaluation Speech and swallow evaluation, potential laryngoscopy Chest x-ray and swallow study, general surgery evaluation
Posterior cervical fusion	New weakness, pain out of proportion to surgery, altered consciousness	Epidural hematoma	STAT CT vs. MRI C spine, immediate evacuation
Anterior lumbar fusion	Abdominal pain, nausea/vomiting, distension	Bowel perforation vs. ileus	Abdominal x-ray, abdominal CT, general surgery evaluation

Table 1.1 Continued

Procedure	Signs/symptoms	Associated complication	Immediate diagnosis and intervention
Posterior lumbar laminectomy/ fusion	Positional headaches worse when sitting up, surgical site leakage Urinary retention, new weakness, abnormal rectal exam	Cerebrospinal fluid leak Epidural hematoma	Flat bedrest, lumbar drain, surgical repair CT vs MRI L spine, immediate evacuation
Cerebral angiogram	Decreased consciousness, focal neurological deficit Severe limb pain, loss of pulses, cold limb, bruising/ hematoma Hypotension, tachycardia, pale skin	Ischemic vs. hemorrhage stroke Hematoma with vascular compromise of limb Retroperitoneal hematoma	STAT head CT, possible decompression vs intervention STAT vascular surgery evaluation, possible cutdown with thrombectomy Check labs, CT abdomen/pelvis, general surgery evaluation, transfuse RBCs if needed

In every scenario, open communication with the surgical team allows for quicker detection and correction of perioperative issues.

Two main options exist for long-term CSF diversion: endoscopic third ventriculostomy and extrathecal drainage (shunting). Endoscopic third ventriculostomy is used primarily for hydrocephalus caused by obstructive pathology blocking flow between the third and fourth ventricle along the cerebral aqueduct. The procedure involves using a neuroendoscope to visualize and fenestrate the floor of the third ventricle, thus connecting the lateral ventricles and third ventricle with the perimesencephalic cistern and the rest of the patient's normal subarachnoid anatomy. Although this technique has enjoyed growing acceptance for applicable pathology, extrathecal drainage remains the gold standard

for treatment. The procedures for shunting are named by the cavities they connect: ventriculoperitoneal, ventriculojugular, ventriculopleural, lumboperitoneal. By far the most common of these procedures is the ventriculoperitoneal shunt.[1]

Procedural Highlights

A ventriculoperitoneal shunt has three components. The *proximal catheter* resides in the ventricle and is connected to the *valve*, which is then connected to the *distal catheter*, which courses underneath the skin down the scalp, neck, chest, and abdominal wall before terminating in the peritoneal cavity. The proximal catheter can have several different trajectories, but the most common is a frontal entry point where the catheter traverses the frontal lobe, entering the frontal horn of the lateral ventricle and terminating in the foramen of Monroe or third ventricle.[2] A more posterior entry point can be used where the catheter passes through the parietal-occipital lobe to enter the atrium of the lateral ventricle and end in the anterior frontal horn. Regardless of the trajectory, placement of the proximal catheter is accomplished by drilling a burr hole, incising the dura, and passing the catheter into the ventricular space. This is done with traditional landmarks or navigation depending on the complexity of the shunt and surgeon preference.

The shunt valve regulates the pressure needed to drain CSF and thus the amount of CSF flow through the shunt system while also providing a reservoir where CSF can be sampled or contrast introduced to evaluate shunt flow under fluoroscopy. Programmable valves are commonly used today and can be adjusted at the bedside or in the clinic using a simple magnetic shunt programmer based on the clinical or radiographic picture.

The distal catheter is the final part of the shunt system. This tube connects to the distal end of the valve and courses beneath the scalp, then down subcutaneously across the neck, chest, and abdominal wall before taking a deep turn into the peritoneal cavity. Thus CSF drained from the proximal catheter passes through the valve, through the distal catheter, and into the peritoneal cavity where it is resorbed.

Perioperative Considerations

The most feared complication in postoperative ventriculoperitoneal shunt placement is intracranial hemorrhage. Placement of the proximal catheter requires passing the catheter through normal brain parenchyma with a stylet or without a stylet through an already present tract due to prior external CSF diversion (soft passing). Trauma from the catheter, with or without the stylet, may result in parenchymal hemorrhage around the tract. Asymptomatic hemorrhage is relatively common, with rates reported as high as 18.1–43.1%.[3] These are often diagnosed on a postoperative head CT routinely obtained to confirm placement of the catheter. However, approximately 2.3% of patients without coagulopathy may experience symptomatic intraparenchymal hemorrhage postoperatively.[3,4] Consequences of such bleeding can be life-threatening, requiring emergent neurosurgical intervention for clot evacuation. Therefore physicians caring for patients undergoing

ventriculoperitoneal shunt procedures should monitor neurological status as well as coagulation studies perioperatively and check the head CT for intraparenchymal hemorrhage.

Injury can also occur anywhere along the body where the distal catheter is passed from the head to the belly. When pushing the tunneler underneath the scalp in line with the neck aiming for the subcutaneous tissue of the chest, a crucial step for the surgeon is ensuring the shunt passer moves superficial to the clavicle. Unintended movements here can injure vascular structures in the neck or dive into the pleural space, resulting in a pneumothorax. Postoperatively, abdominal injury is also important to consider because approximately 10–30% of ventriculoperitoneal shunt complications arise within the abdominal portion of the procedure.[5] Bowel perforation, if suspected, requires emergent upright abdominal x-rays, CT of the abdomen, and concomitant emergent general surgery consultation. Delayed abdominal complications include cerebrospinal loculation or pseudocyst formation, catheter migration into the subcutaneous tissue, pericapsular hepatic cystic formation, or even remote perforation due to catheter erosion into the bowel wall over time. Suspected pathology can be evaluated with an abdominal ultrasound (can be used to visualize a pseudocyst), upright x-rays, or, most definitively, a CT scan with and without contrast.

Shunt infection and shunt failure are the other two main postoperative problems that require a formulaic approach to both diagnose and properly manage. Shunt failure is defined as failure of the shunt's ability to meet the drainage requirements of the CSF in an individual. This can be due to obstruction (partial or complete), hardware/valve failure, or increased CSF production outstripping drainage capabilities. If either is suspected, the workup starts with the clinical exam and history, lab work, and cultures, and then proceeds to noninvasive imaging. If this does not identify an obvious shunt malfunction (e.g., ventricles are larger than the patient's baseline), more invasive testing can be performed that is aided by the shunt valve itself. All shunt valves include a reservoir that the neurosurgeon can tap to sample CSF for cultures and cell counts. Also, contrast can be injected under fluoroscopy to visualize the patency of the system.

Patients with infected shunts often present with two main symptoms: fever and shunt failure. Routinely a noncontrasted CT scan of the head is needed as well as a shunt series consisting of x-ray films to demonstrate the continuity and location of the system. Ventriculomegaly compared to a previous scan indicates shunt malfunction, and kinks or disconnections can be diagnosed on the shunt series. In the patient with abdominal pain, an ultrasound is a good first step to evaluate for a pseudocyst, although the most helpful image will be a CT of the abdomen and pelvis with and without contrast. Fever, especially within the first 6 months of implantation, should raise suspicion for device infection, yet tapping the shunt is avoided if possible until other sources of fever are ruled out. This is because interrogation of the shunt by percutaneous tap has a small but understandable risk of infecting a previously sterile shunt system.[6] Bacterial etiology of shunt infections are most often skin flora; *Staphylococcus epidermidis, Staphylococcus aureus, Escherichia coli, Pseudomonas* spp., and *Klebsiella* spp. are the bacteria with the highest incidence of

shunt infection with *S. epidermidis* being the most common.[3,5] Shunt infections require shunt removal, hospitalization for extracorporeal CSF drainage during an extended course of antibiotic treatment, and then reimplantation of a new shunt once the infection has cleared.

CRANIOTOMY AND CRANIECTOMY

Indications

Craniotomy refers to temporarily removing a portion of the skull. When the bone is left off after the intracranial operation is complete, this is a *craniectomy*. Both craniotomies and craniectomies are very common procedures indicated for a wide variety of reasons. Only several scenarios will be discussed here. The first is craniotomy or craniectomy for tumor resection. Reasons for tumor resection can be divided into diagnostic, neurologic, and oncologic. In order to begin treatment, whether systemic or local, radiation and medical oncologists generally require pathology to plan treatment. If no safer lesion for biopsy is identified with a systemic workup (PET scan, CT C/A/P, lumbar puncture, etc.), then a craniotomy may be performed to obtain tissue for pathology in the form of a stereotactic brain biopsy or open resection. Mass effect causing neurological impairment or even hydrocephalus may also require craniotomy for tumor resection or debulking. Finally, depending on the type and location of the tumor as well as the patient's condition and comorbidities, resection or debulking can help with oncologic control and improve survival.

Craniectomy, or leaving the bone off after a craniotomy, is performed in order to allow for severe brain swelling usually caused by large ischemic strokes (malignant middle cerebral artery [MCA] syndrome), intracranial hemorrhages, or trauma. This is done to prevent or relieve pressure on the uninjured brain. There is a wide body of literature supporting craniectomy for the treatment of such patients.[7–9]

Procedural Highlights

In positioning for many craniotomy/craniectomy procedures, the surgeon may elect to have patients placed in a Mayfield three-prong head holder to keep the head fixed in position during a delicate procedure. This device is used to apply 60–80 pounds of force clamping the skull in rigid fixation. Calvarial exposure is accomplished with incisions designed to respect the scalp's blood supply and avoid tissue ischemia during wound healing. Once the skull is exposed, the craniotomy is planned and carried out with several burr holes that are placed with a high-speed drill and then connected using the same drill with a saw attachment. The bone flap is then removed. Of note, the neurosurgical "workhorse" is the pterional craniotomy, which requires dissection and detachment of the temporalis muscle—an aspect of the procedure that often can cause pain during talking and chewing in the postoperative period. The bone removal exposes the dura, which is then cut open, reflected, and then tacked up to reveal the underlying brain.

At this point, the procedure will vary depending on the goal of surgery: dissection begins, and the tumor is resected, the aneurysm is clipped, the clot is removed. During the final phase of surgery, dural edges are reopposed and sutured shut. The bone is then reimplanted using a metal plating system. For craniectomies, the bone is either discarded or sent to a freezer for storage and the scalp is sewn shut, covering the dura. These patients return months later to undergo a cranioplasty procedure where the bone flap or a synthetic implant is placed. Both craniectomy and craniotomy procedures commonly have a temporary drain with bulb suction, which helps to prevent hematoma accumulation in the surgical site and is often removed on post operative day 1 or 2.

Perioperative Considerations

Depending on the pathology being addressed by the craniotomy or craniectomy, specific medical issues arise perioperatively. Many of these will be discussed in subsequent chapters, but some general issues applicable to craniotomies deserve mention. First, and perhaps most importantly, is close attention to the neurological exam. Any negative changes should be emergently relayed to the neurosurgical team and will usually mandate a head CT. Strict blood pressure control based on either mean arterial pressures or systolics is meant to prevent postoperative hemorrhage in the tumor bed. Antiepileptics are often given perioperatively at the discretion of the surgeon. Tumor patients are commonly on high-dose dexamethasone to combat vasogenic edema preoperatively, and a plan for the steroid taper usually starts after the operation. Mannitol and furosemide (Lasix) are commonly given during the case to combat brain swelling and so renal function and fluid balance should be monitored postoperatively.[10,11] Deep vein thrombosis prophylaxis can usually resume on postoperative day 1, but should be judiciously dosed by weight to avoid increasing the risk of hemorrhagic complications. Complications of the procedure will also dictate perioperative medical concerns. For instance sacrificing a draining vein or sinus during the course of the surgery will predispose a patient to venous infarction, and so this patient will require generous hydration.

Finally, while cranial incisions are planned to respect the scalp's major blood supply, these patients are at high risk of wound breakdown and infection. Factors that may be modified to improve outcomes include glycemic control perioperatively and nutritional status.[12,13] Especially in oncologic patients, nutritional supplementation provides support to wounds that often undergo postoperative radiation. Hyperglycemia in postoperative patients is associated with increased infections and return to the operating room for cranial wound revision. By modifying these factors perioperatively, outcomes may be improved.

CERVICAL DECOMPRESSION AND FUSION

Indications

Cervical decompression and fusion procedures have many indications including myelopathy, radiculopathy, trauma, deformity, and instability. By far the most common

are cervical myelopathy and traumatic fractures or nonunions. These tend to require central canal decompression and fusion of multiple levels. Depending on the extent and location of pathology (ventral or dorsal), patients may undergo anterior or posterior approaches, or both. If the primary indication is radiculopathy, patients may only require decompression in the form of foraminotomies or laminectomies. In general, the less bony work necessary to achieve neural decompression, the lower the chance of creating iatrogenic instability requiring fusion.

Procedural Highlights

Surgeons may take either an anterior or posterior approach to the cervical spine. The choice of approach is patient-specific, taking into account location of pathology (ventral vs. dorsal) and the goals of surgery. The anterior approach involves an incision off the midline of the neck, often in a natural fold or crease in the skin. Platysma is divided and an avascular plane medial to the sternocleidomastoid dissected, leading to the carotid sheath. The carotid is then retracted laterally and the esophagus medially, exposing the anterior vertebral body. Discectomy is performed and an interbody fusion device is placed, usually along with a plate and screws in adjacent vertebrae. In this way anterior decompression and fusion is achieved. Bleeding is controlled, a drain can be placed, and the platysma is reapproximated with sutures. Skin may be sutured or closed with a topical skin adhesive (Dermabond) per surgeon preference.

Cervical pathology may also be addressed with a posterior cervical decompression and fusion. For this procedure, the patient normally has the head placed in cranial pins to hold the neck in alignment during the procedure. The paraspinal musculature is dissected down to the spinous processes and off the edge of the lateral masses. Screws are placed in the lateral masses to stabilize the spine for bony fusion. Spinous process and lamina are drilled off to create more room in the spinal canal for the neural elements. Afterward a drain is placed and layers of muscle, fascia, fat, and skin are closed.

Perioperative Considerations

During the anterior cervical approach, critical structures encountered include the esophagus, trachea, carotid artery, internal jugular vein, vagus nerve, recurrent laryngeal nerve, and superior laryngeal nerve. From working around these structures, common perioperative medical issues are centered around breathing and swallowing function. Esophageal perforation is a rare but feared complication occurring with an incidence of 0.02–1.52%.[14] Patients may encounter increased sputum production, cough, pain on swallowing, vomiting, and sepsis. The workup may require a swallowing study or CT imaging, antibiotics, and corrective surgery if these concerning symptoms are observed.

While intubation may cause irritation and trauma, hoarse voice, coughing, or aspiration raises concern for the possibility of recurrent laryngeal or superior

laryngeal nerve injury during surgery.[14,15] This is a concerning morbidity as nerve damage here will raise the long-term risk of aspiration for patients. Disruption of swallowing function is especially a concern in elderly patients. If swallowing function is a concern, patients may receive a course of steroids to decrease swelling from intubation and surgery. Often this is enough to alleviate symptoms. Further workup of these symptoms includes speech and swallow evaluation, and subsequent laryngoscopy by an otolaryngologist will be required to investigate vocal cord function. On occasion, the vocal folds may be injected with a collagen-like substance to address glottal insufficiency in postoperative patients with vocal cord paresis.[16]

Lastly, careful attention should be paid to respiratory function in the immediate postoperative care of anterior cervical procedures. If bleeding is uncontrolled, damage to the carotid sheath occurs; or, if the drain left intraoperatively does not function correctly, a hematoma may form and compress the airway. In these instances intubation is can be difficult and the patient may need the surgical wound emergently opened at bedside to relieve pressure on the airway.[14]

Whereas the dissection for the anterior approach takes advantage of natural tissue planes between the neck musculature to reach the ventral spine, the posterior approach cuts and retracts the musculature overlying the dorsal spine. Therefore, while possible injury to the esophagus, jugular vein, recurrent laryngeal nerve, and carotid artery is avoided, this approach invariably results in more postoperative pain compared to the anterior approach. The pain should be managed with judicial use of narcotics and muscle relaxants. Severe pain, especially pain that increases after a period of initial improvement, should raise suspicion for a postoperative hematoma and requires emergent attention. Since the lamina has been removed in most cases, a mass lesion here can directly compress the spinal cord, leading to potentially irreversible sensory changes or weakness.[17] Usually emergent imaging (MRI provides a better image but a CT can also demonstrate a postoperative hematoma more quickly) will be followed by an emergent return to the operating room for evacuation.

Regardless of the approach, patients who undergo cervical decompression or fusion are at risk for a postoperative C5 palsy which manifests as deltoid weakness. This is a phenomenon that is well described but not completely understood. The C5 nerve root is presumed to be at greater risk for injury after a decompressive procedure due to the angle at which it leaves the spinal cord. One of the proposed mechanisms is tethering of the nerve root after the spinal cord is decompressed and moved dorsally. However, segmental ischemia and reperfusion injury from disruption of radicular vasculature has also been proposed. This occurs in 4–8% of these cases.[18,19] In studies comparing the incidence of C5 palsy in cervical approaches, ventral approaches (4.3%) had a lower incidence of C5 palsy than dorsal approaches (10.9).[18] There have been studies suggesting that perioperative steroids may be of benefit, but most studies suggest that high-dose steroids may delay fusion, and the majority of these patients ultimately improve on their own.